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Load-Following Strategies for Evolution of Solid Oxide Fuel Cells Into Model Citizens of the Grid

Allie E. Auld, Jack Brouwer, Keyue Ma Smedley, *Senior Member, IEEE*, and Scott Samuelsen

Abstract—Proper converter design can allow solid oxide fuel cells operated as distributed generators to mutually benefit both the load and the electric utility during steady-state conditions, but dynamic load variations still present challenges. Unlike standard synchronous generators, fuel cells lack rotating inertia and their output power ramp rate is limited by design. Two strategies are herein investigated to mitigate the impact of a large load perturbation on the electric utility grid: 1) external use of ultracapacitor electrical storage connected through a dc–dc converter and 2) internal reduction of steady-state fuel utilization in the fuel cell to enable faster response to output power perturbations. Both strategies successfully eliminate the impact of a load perturbation on the utility grid. The external ultracapacitor strategy requires more capital investment while the internal fuel utilization strategy requires higher fuel use. This success implies that there is substantial flexibility for designing load-following fuel cell systems that are model citizens.

Index Terms—Active power filter (APF), distributed generation (DG), fuel cell, fuel utilization, inverter, modeling, one-cycle control, power quality, ultracapacitor.

I. INTRODUCTION

THE UNITED STATES is moving toward an increasingly electrified society. The portion of U.S. total energy use for electricity production grew from 27% in 1974 to 36% in 1989, and is projected to reach 46% by 2010 [1]. In parallel, this growing dependence is emphasizing the need for reliable, high-quality power [2]. Distributed generation (DG), which is power generated near the site of its use, can help solve many of the issues associated with the societal and environmental impacts of this increased power usage. Fuel cells are one type of distributed generation technology that have low emissions and high efficiency, particularly with combined heat and power applications [3], and the solid oxide fuel cell (SOFC) is a type of high-temperature fuel cell that is being actively developed both privately and publicly [4], [5].

Yet, as the application opportunities for SOFC technology increase, so does the need to understand the potential dynamics

that they will add to the electric utility grid [6]. Fuel cells are typically interfaced with the grid through inverter-based technology, which may introduce new dynamic characteristics that must be well understood before they become widely accepted. Ideally, fuel cells can become “model citizens” of the utility grid, which means their implementation will improve grid performance. Good citizens have a neutral effect, and poor citizens have an adverse effect.

The addition of an active power filter (APF) to the DG inverter connection is shown in [7] to improve the grid tie-line current by lowering total harmonic distortion and increasing the power factor of imported power to unity. These qualities are advantageous, so under steady-state conditions, an SOFC can demonstrate features of a model citizen. Yet, dynamic load perturbations are still a major issue for DG applications of fuel cells. In the grid-connected mode, rapid load changes can result in short current surges, which are a highly undesirable poor citizen behavior that can affect grid stability. When not connected to the grid, there is no buffer between load and fuel cell, so a sudden load perturbation can create a power deficit that may harm the load and/or the fuel cell.

There is a wide variety of external energy buffers available for fuel cell systems. Incorporating batteries into the power conversion system is a strategy used by Choi *et al.* [8], and Auld *et al.* [7] and Wen *et al.* [9] both show that a load transient can be met with a large dc capacitor. An emerging method of energy storage uses ultracapacitors, which have a higher energy density than normal capacitors and faster response time than batteries [10]. Ultracapacitors have been investigated for providing energy storage in automotive, residential, and commercial applications [10]–[12].

While external energy storage devices and power electronics can help the SOFC system behave as a model citizen, internal SOFC load-following capability is desirable. The SOFC stack itself operates on an electrochemical timescale of milliseconds [13] and responds to load perturbations at this timescale as long as fuel and oxidant are present in sufficient quantities in the respective electrode flow channels (anode and cathode). Unlike traditional generators, SOFC systems do not have rotating inertia that can be used to both buffer the system during perturbations and produce additional power (e.g., spinning reserve). But the inherent SOFC load-following capability is severely limited by the balance of plant response characteristics and safety considerations that can increase the typical SOFC system response time to seconds, minutes, or even hours.

Most importantly, sufficient fuel must be provided by the fuel supply and fuel processing components of the system in proportion to the power demanded. The fuel cell always requires

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more fuel than is electrochemically consumed to produce electricity; the ratio of consumed to provided fuel is defined as the utilization, U

$$U = \frac{N_{\text{consumed}}}{N_{\text{in}}} \quad (1)$$

If the stack has sufficient fuel available when the power demand is increased, then it will be able to increase output more quickly than if it must wait for more fuel. This is the main principle of the utilization-based control strategy: deliver excess fuel to the stack at all times to facilitate faster response to load perturbations. Note that this strategy may require more steady-state fuel use and lower system efficiency unless it is only applied during periods when large power demand increases are expected (e.g., when building air conditioning equipment is turned on in the morning).

This paper investigates possible methods for improving grid-connected fuel cell dynamic performance during load perturbations. Measured dynamic load data from a southern California office building are used as the typical perturbation. The load data are combined with physically based and experimentally validated models of an inverter, APF, SOFC, and ultracapacitors with dc/dc converter in MATLAB/SIMULINK. The two strategies explored are: 1) using ultracapacitors for storing electrical energy and 2) reducing the steady-state SOFC fuel utilization. Both methods are found to produce model citizen behavior of the grid-connected SOFC system.

II. MODEL COMPONENTS

A. Dynamic Load Data

Meacham *et al.* shows in [12] that power monitoring of a typical commercial southern California office building provided insight into building load behavior. The most dramatic daily load change is associated with the air conditioning system turning on in the early morning hours and shutting down at around 5 P.M. The three-phase voltage and current entering the building during this worst case morning transient are recorded with a Nexus 1270 power quality monitor. The data are sampled at 128 samples/cycle, or 7680 Hz, and the resulting instantaneous power calculation is presented in Fig. 1. The high-frequency oscillations are due to the harmonics and unbalanced phases that occur with practical loads.

B. Power Electronics Models

The one-cycle control (OCC) inverter (Fig. 2) and the OCC APF (Fig. 3) are described by Qiao and Smedley in [14], Qiao *et al.* [15], [16], and Jin and Smedley [17], and the MATLAB/SIMULINK models are discussed along with experimental verification in [18] and [19]. Both are implemented with the OCC strategy and the switching flow graph method, which are fully described by Smedley and Čuk in [20] and [21]. The inverter and APF each use a three-phase half-bridge converter topology with six switches. The grid voltage and current is sensed, and the complete 360° line cycle is divided into six –60° regions. In each region, only two switches are actively controlled. The key control equation describes how the duty

Fig. 1. Dynamic load data measured during early AM transient and sampled at 7680 Hz.

ratio for these two switches is calculated from other system parameters.

The key control equation for the OCC inverter is presented in (2) [14] and that of the OCC APF is presented in (3) [16]

$$R_s \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} i_p \\ i_n \end{bmatrix} = \begin{bmatrix} KV_p - V_m d_p \\ KV_n - V_m d_n \end{bmatrix} \quad (2)$$

$$V_m \begin{bmatrix} 1 - d_p \\ 1 - d_n \end{bmatrix} = R_s \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \begin{bmatrix} i_p \\ i_n \end{bmatrix} \quad (3)$$

where R_s is the equivalent sensing resistance, K is a near-constant that limits output current for the inverter, V_m is an introduced variable, i_p and i_n are selected injection currents, d_p and d_n are the respective duty ratios for switches p and n , and V_p and V_n are selected linear combinations of grid voltages V_a , V_b , and V_c .

C. SOFC Model

A physically based SOFC model was previously developed in MATLAB/SIMULINK using a modeling methodology that was validated with experimental data from a 220 kW SOFC-MTG hybrid system in [22], dynamic single-cell transients in [23], and integrated simple-cycle SOFC systems in [24]. The model used herein is simplified for integration with power electronics, as described in [7]. The cell voltage is calculated as the Nernst potential minus the activation, ohmic, and concentration polarizations, according to the standard form found in [25]. The full SOFC stack model is created by adjusting the number of cells in parallel and their size to reach a capacity of 100 kW.

The rate of fuel consumption is proportional to current according to Faraday's law (4)

$$\dot{N}_{\text{consumed}} = \frac{i}{nF} \quad (4)$$

where $\dot{N}$ is the molar flow rate of electrochemically active fuel constituents, such as hydrogen, i is the current produced by the cell, n is the number of electrons participating in the reaction, and F is Faraday's constant: 96 487 C·mol⁻¹.

Fig. 2. (a) Power stage circuit diagram of OCC inverter; (b) large-signal switching flow graph model of OCC inverter [18].

Fig. 3. (a) Power stage circuit diagram of OCC APF; (b) large-signal switching flow graph model of OCC inverter [19].

The hydrogen flow rate that should be delivered to the SOFC stack can, thus, be calculated according to the desired current output. Sufficient hydrogen must always remain within the anode compartment to prevent hydrogen starvation, so the hydrogen delivered must exceed the amount actually consumed. This ratio is called the utilization U , and is defined previously in (1). The utilization also affects the SOFC system efficiency η , as shown in (5)

$$\eta_{\text{SOFC}} = U \frac{V_{\text{cell}}}{1.25}. \quad (5)$$

Therefore, the required flow rate to maintain utilization can be calculated directly, as presented in (6), according to the current-based fuel control strategy that is discussed in detail by Mueller *et al.* [26]

$$\dot{N}_{\text{in}} = \frac{i^*}{U n F}. \quad (6)$$

The current demand i^* is approximated from a lookup table according to power demand and cell voltage. During load transients, the fuel flow into the anode compartment takes a finite time to increase. To avoid hydrogen starvation during this period, the current is limited by i_{max} , which is defined as the current generated at a set maximum utilization U_{max} , and the delayed inlet hydrogen flow rate, as shown in (7)

$$i_{\text{max}} = \dot{N}_{\text{in,delayed}} U_{\text{max}} n F. \quad (7)$$

This strategy can avoid the risk of hydrogen starvation while allowing some internal SOFC capability to load follow within a range of fuel utilization. The hydrogen delivery delay is modeled herein as a fixed 2 s delay, which could be caused by a slow sensor, valve actuation, reformer dynamic, or other physical process.

The response of this 100 kW SOFC model to a step load change from 30 to 60 kW is presented in Fig. 4. There is a modest initial increase in the power output as the SOFC utilization increases to try to meet the power demand increase perturbation at 5 s. Yet, the maximum utilization is set at 0.9, so after this utilization is reached the SOFC cannot increase the power output until more fuel is delivered at 7 s, corresponding to the fuel delay of 2 s. Then, the fuel delivered becomes sufficient to meet power demands and fuel utilization returns to its original steady-state value.

D. Ultracapacitor Model

Ultracapacitors have a much higher capacitance than other capacitors because they combine the benefits of close electrode spacing with porous electrodes that increase surface area [27]. The addition of porous electrodes is what differentiates ultracapacitors from dielectric ones, but it creates more complex electric behavior as well. Fig. 5(a) shows a simple capacitor model: there is a bulk capacitance in parallel with leakage

Fig. 4. SOFC model response to an increased load change as a function of hydrogen utilization.

Fig. 5. Comparison of simple capacitor and ultracapacitor models: (a) capacitor equivalent circuit, (b) ultracapacitor equivalent circuit [27].

resistance, and in series with R_{esr} , which represents the equivalent series resistance. The ultracapacitor has macro-, meso-, and micropores that subsequently create fast, medium, and slow time constants. As presented in Fig. 5(b), the different pore sizes create two additional circuit components in parallel with the bulk capacitance [27].

Although ultracapacitors have high capacitance, they tend to have low voltage per cell. The ultracapacitor type investigated here is the 2.5 V and 2500 F product of Maxwell Technologies. This creates an equivalent energy storage of 7.8 kJ, though the capacitors can only be safely discharged to half of their maximum voltage, making the usable energy storage around 5.8 kJ. According to Miller *et al.* [10], the single-cell model can be extended to an arbitrary scaling of N cells connected in series. This equivalent circuit schematic is shown within the dotted lines of Fig. 6 and the corresponding constants are listed in Table I, where $\phi = 0.5(\sqrt{5} - 1)$, $j = 2$, and $k = 8$. R_{esr} , C_0 , and R_{lk} are properties of the capacitors, and are 1 m Ω , 2500 F, and 3 k Ω , respectively, for the 2.5 V ultracapacitors.

Fig. 6. Circuit schematic for dc-dc converter.

TABLE I
TIME CONSTANTS FOR SCALED N -CELL ULTRACAPACITOR MODEL

Fast	$R_f = \frac{2N}{3} R_{esr}$	$C_f = \frac{1.05}{N} C_0$
Medium	$R_m = \frac{2N}{3} \phi^{-(2k-1)} R_{esr}$	$C_m = \frac{1.05}{N} \phi^{+(2j+1)} C_0$
Slow	$R_s = \frac{2N}{3} \phi^{-(2k+1)} R_{esr}$	$C_s = \frac{1.05}{N} \phi^{+(2j-1)} C_0$
Leakage	$R_{leak} = NR_{lk}$

Fig. 7. Switching flow graph and PID feedback control for the dc-dc converter with ultracapacitor bank with impedance Z_C .

E. DC-DC Converter Model

The bidirectional dc-dc converter is a buck converter that is modified to allow current flow in both directions. The simple circuit schematic for the dc-dc converter is presented in Fig. 6. The equivalent switching flow graph model, also developed according to the methodology in [21], is presented in Fig. 7.

The bulk impedance, Z_C , of the ultracapacitor bank is calculated from the constants in Table I and the resulting transfer function is incorporated into the dc-dc converter from Fig. 7. A closed-loop feedback PID control of duty ratio is also added to govern the charge and discharge of the ultracapacitors. The reference input is the desired average current absorbed from the high voltage source. The other input is V_g , which is the voltage of the dc bus that connects the SOFC to the inverter.

An iterative study of PID parameters for best control of the dc-dc converter led to the selection of the following PID constants: $p = 0.5$, $i = 0.15$, and $d = 0$.

III. DYNAMIC EFFECT OF NO LOAD-FOLLOWING

The baseline case is a basic interconnection of SOFC, inverter, APF, load, and grid, as presented in Fig. 8. This case utilizes the identical SOFC model from Fig. 4 applied to the measured load dynamic recorded from the office building. The load power is calculated instantaneously and low-pass filtered to create P_{load} . The APF eliminates the harmonics that create

Fig. 8. Block diagram of control scheme with inverter/APF and SOFC.

Fig. 9. SOFC response with no load-following strategy: (top) DG power and demand and (bottom) rms grid current.

the high-frequency oscillation, so this is the equivalent power demand. A set amount of power, P_{grid} , is imported through the tie-line at all times. For this simulation, P_{grid} is set to 10 kW. So, the desired power demand P_{demand} is P_{load} minus P_{grid} .

The shunt APF filters the load by injecting currents to balance the phases and compensate harmonics. The line current i_{line} provided by the utility grid is the load current i_{load} minus the current generated on-site with the SOFC, i_{inv} , and filtered with the APF. The *abc* designation of the currents and voltages in Fig. 8 indicates that each is comprised of three phases.

The resulting power and rms grid current are presented in Fig. 9. Because the SOFC power increase lags substantially behind the power demand and there is no other distributed source of power, the deficit is met by an increase in the per phase grid rms current, as presented in Fig. 9. When the SOFC is able to meet the new load demand, the grid current returns to its steady-state value. But this “load spike” is indicative of the poor citizen behavior that SOFC implementation should avoid, which necessitates the implementation of a load-following strategy.

IV. ULTRACAPACITOR-BASED LOAD-FOLLOWING

The external electrical energy storage load-following strategy involves connecting a bank of ultracapacitors to the dc bus through a dc/dc converter, as presented in Fig. 10. The actual power delivered to the inverter is P_{INV} , which is the combination of the SOFC power, P_{SOFC} , and the power output of the ultracapacitors.

Fig. 10. Block diagram of control scheme with inverter/APF, SOFC, and ultracapacitors connected by dc/dc converter.

Fig. 11. Load-following matching and tie-line grid current for SOFC and ten ultracapacitors: (top to bottom) DER power and demand, ultracapacitor voltage, and rms grid current.

Feedback between the ultracapacitor voltage and the SOFC allows the ultracapacitors to charge and discharge as needed. When there is a deficit between the SOFC power and the desired power, the ultracapacitors discharge and the difference between reference and actual voltage is measured and added to the SOFC demand power through a PID controller. When the SOFC can meet the power demand, excess SOFC power is used to recharge the ultracapacitors until the next dynamic load change or the ultracapacitors reach full charge.

The minimum number of ultracapacitors required to completely meet the power demand during the transient is ten, which is calculated by running the simulation for a wide range of capacitance values. For this case, the system is limited by the maximum output power of the ultracapacitors (1.4 kW per cell) and not by the total energy storage required. The result for the system simulation that includes ten ultracapacitors is presented in Fig. 11. The power demand and inverter power exactly overlap, so there is no power deficiency that must be provided by the grid. The ultracapacitors then recharge with a moderate increase in SOFC power setpoint. The ultracapacitor voltage presented in the middle graph of Fig. 11 decreases during discharging, and then returns to the maximum fully charged value. The bottom

Fig. 12. Load-following matching and tie-line grid current for SOFC and five ultracapacitors: (top to bottom) DER power and demand, ultracapacitor voltage, and rms grid current.

graph shows the rms line current delivered from the utility grid. Each of the three phases overlaps, which indicates successful phase balancing. The line current is also flat during the entire transient, which indicates that the load dynamic has become invisible to the utility as a result of effective SOFC load-following capability. This ability to reduce transients indicates model citizen behavior.

A separate system design that only utilizes five ultracapacitors is also investigated for the same dynamic power demand scenario. The simulation results for this five-ultracapacitor case are presented in Fig. 12. The inverter power can match the power demand temporarily until it falls deficient at 3.7 s. In this case, the ultracapacitors are limited by the maximum power output, so the inverter power cannot exceed a fixed value above that which the SOFC can provide, as shown in the top graph of Fig. 12. The middle graph shows the change in voltage across the ultracapacitors as they are discharged and recharged. Fewer capacitors in series cause lower total voltage. The bottom graph of Fig. 12 shows the rms grid current delivered by the grid. It is mostly constant, except for an increase during the time period when the inverter-delivered power falls short of the power demand. This grid impact is less desirable than that of the ten-ultracapacitor case, but better than an interconnection strategy with no load-following provision.

The main factor in determining the delay in SOFC power output increase is the fuel flow delay, which is approximated as a 2 s delay. If the SOFC system has a different delay, the number of ultracapacitors required to meet the measured dynamic load would change in turn. A sensitivity analysis of fuel delivery delay times from 1 to 6 s was conducted. The corresponding number of ultracapacitors required to meet the building power demand perturbation, without changes in rms grid current for each delay time, is presented in Table II. The number of ultracapacitors is limited by the maximum power output from 1–4 s delay and by maximum energy storage requirements for 5 and 6 s delay situations. The most ultracapacitors required is 22 for a 6 s delay, which is still a reasonable number for integration

TABLE II
NUMBER OF ULTRACAPACITORS AS A FUNCTION OF TIME DELAY

Time delay (s)	Number of Ultra-capacitors
1	4
2	10
3	14
4	16
5	19
6	22

with a 100 kW SOFC system installation. These results imply that while the number of ultracapacitors is strongly dependent on the response of the SOFC system, the same final behavior can be achieved regardless of the exact system fuel flow delay characteristics. Note, however, that requiring a larger number of ultracapacitors will increase system capital cost.

V. FUEL-UTILIZATION-BASED LOAD-FOLLOWING

Adding external electrical storage with ultracapacitors is more viable than with a single dc capacitor, but can still be bulky and expensive. It was previously stated that SOFC output current is fundamentally limited by the amount of electrochemically active fuel constituents in the anode, which is a function of the fuel utilization. Lowering the fuel utilization directly lowers efficiency, but increases the amount of extra fuel that is present at any time in the anode compartment. During a transient, this extra fuel can be immediately reacted to provide additional current. The utilization-based load-following method uses this internal method of operating the SOFC to inherently produce better load-following capability. To demonstrate this strategy without any external electrical storage, the power demand P_{demand} is calculated in the same way as described earlier, thus becoming the power reference for the SOFC. The resulting SOFC power is inverted by the three-phase inverter and injected onto the bus. Since there is no external load-following strategy (i.e., no electric energy storage), the system can only provide as much power as the SOFC can produce.

A sensitivity analysis showed that a maximum steady-state fuel utilization of 0.55 is required to completely match the power demand perturbation. Fig. 13 shows the utilization juxtaposed with the power demand and the tie-line grid current for the case when steady-state utilization is 0.55.

The lack of external electrical storage causes the SOFC to meet the entire power demand perturbation. This occurs because the utilization, which is the middle plot in Fig. 13, begins to steadily increase in parallel with the power demand change during the transient. The SOFC output can now match the demand without waiting for additional fuel, because the necessary fuel is already present within the anode compartment. When new fuel enters the anode compartment, the utilization returns to its desired steady-state value. The resulting grid tie-line produces no spike, so the utilization-based SOFC control strategy improves the system load-following capability. This comes at the expense of efficiency, as shown in Fig. 14. The theoretical efficiency is directly related to the utilization, as shown in (5), so the efficiency of the case with lowered utilization (dotted line) is consistently lower than the case with standard utilization

Fig. 13. Load-following matching and tie-line grid current for SOFC with steady-state utilization of 0.55: (top to bottom) DER power and demand, SOFC utilization, and rms grid current.

Fig. 14. Comparison of theoretical efficiency for standard SOFC and SOFC with reduced steady-state utilization.

(solid line). Note that the standard utilization case requires external electrical storage to meet the power demand perturbation without introducing a grid power spike.

A sample of the three-phase voltage and current for the internal fuel utilization control strategy case is shown in Fig. 15. The top two graphs, representing line voltage and load current, are experimentally measured directly from an office building. The inverter current is the simulated current produced from the inverter and SOFC, and the grid current is the anticipated actual current generated from the utility grid.

As a result of the SOFC installation with fuel-utilization-based load-following and advanced interconnection strategy, the new grid current has reduced magnitude, lower harmonic distortion, unity power factor, and balanced phases. This means that the installation of DG at this site has improved the impact of the load on the utility grid network. Both power-quality-related improvements at steady state and elimination of a large current transient during the dynamic perturbation are achieved, which indicates model citizen behavior. Similar improved power quality results are observed for the ultracapacitor case, but only the utilization example is shown to avoid redundancy.

Another way for assessing the overall effect of adding DG to a load is to compare the instantaneous power provided to each step of the process. In Fig. 16, the top graph shows the measured instantaneous load demand, which are the same data

Fig. 15. Closeup of voltage and current waveforms for utilization-based load-following strategy: (top to bottom) line voltage, load current, inverter current, and grid line current.

Fig. 16. Instantaneous power at different points in the DG/load system: (top to bottom) power to load, power to SOFC and load, and power provided by utility.

presented in Fig. 1. At this stage, there are both high-frequency oscillations and changes in the average power demand. The middle graph shows the instantaneous power provided to the DG/load combination by the grid. The average power is constant here, but the high-frequency oscillation is still present. The APF removes this high-frequency oscillation, and the resulting power provided by the grid is constant, as shown in the bottom graph of Fig. 16. So, even during the worst case load transient of the day, appropriate power electronics design and control can turn a complex system of dynamic load and dynamic SOFC into a simple, linear, constant power load. This result is beneficial to the utility, and implies that well-designed SOFC-based DG can be a model citizen asset for the utility grid as well as to the user.

Building performance monitoring reveals that the daily worst case load demand perturbation is associated with air conditioning system starts. Using the SOFC fuel utilization control strategy, the controls of the air conditioning system could be

coupled with the SOFC system, thereby allowing the air conditioning system to preemptively signal the SOFC that it is ready to turn on. The SOFC fuel utilization could then be dropped momentarily to allow the load dynamic to be absorbed by the SOFC while still maintaining a high overall system thermodynamic efficiency during steady-state operation.

VI. SUMMARY AND CONCLUSION

A load-following strategy using either ultracapacitors or fuel utilization with an SOFC is able to reduce or eliminate the effect of a dynamic load perturbation on the utility grid. Along with an APF, proper design of an SOFC interconnection can produce model citizen behavior by improving power quality and eliminating erratic power demands.

Communication between building equipment and the SOFC system could enable operation with high steady-state efficiency and good load-following capability by using the fuel utilization control strategy only when perturbations are expected. The ultracapacitor strategy can buffer the SOFC in cases where the load is less predictable, thereby mitigating the impact of the dynamic load swing on the utility.

The ultracapacitor strategy requires more capital investment while the fuel utilization strategy leads to lower efficiency. Both successes imply that there is substantial flexibility for designing load-following fuel cell systems that are model citizens.

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